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DISCONNECT CONNECTORS TO CARBON FIBERS
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VULNERABILITY OF QUICK DISCONNECT CONNECTORS
TO CARBON FIBERS

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Hampton, Virginia 23665

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SUMMARY

This effort is a part of the Graphite Fiber Risk Analysis Program and is directed at providing data to enable forecasting the exposure to failure of electronic devices. Unprotected connectors are one of the most vulnerable parts of an electrical appliance or unit.

Quarter inch quick disconnect electrical connectors were tested by mounting on a board. Fourteen connectors were spaced at 1/4 inch (6mm), 1/2 inch (13mm) and 3/4 inch (19mm). They were exposed to fibers of 3mm, 7mm and 12mm lengths with the exposure required to produce a short determined. Shorting bars were also included in the testing to simulate a fiber shorting from the connector to an appliance case.

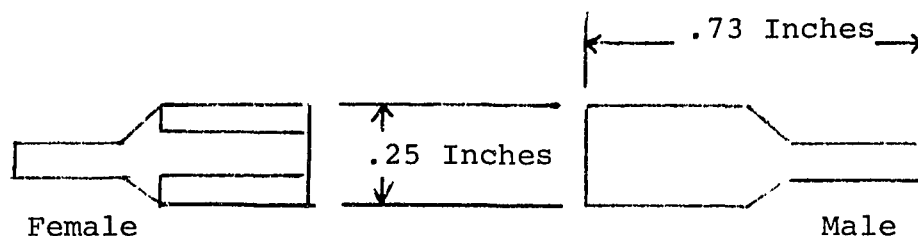
Six test runs were made at each fiber length. The average exposure to failure was plotted against the ratio of Fiber Length/Airgap. Knowing the Fiber Length/Airgap ratio the average exposure to failure for this type connector may be obtained if the plot is normalized to the number of connectors in question. Lower exposures to failure are seen to the right of the point where the fiber length divided by the airgap is one. Below this point multiple fibers are required to bridge the gap and the exposure to failure rises rapidly. Figure 14 shows a combined plot and boundary limits of the values obtained from it.

1.0 Introduction

This work was accomplished under the Graphite Fiber Risk Analysis Program. It is a part of other testing being done on appliances and electrical devices. Since unprotected connectors are probably the most vulnerable part of an electronic unit it is believed data on connectors will provide insight into the exposure levels at which electronic units may fail. The objective was to secure data relating the exposure to carbon fibers and the occurrence of shorts across electrical connectors with various spacings or airgaps. Test results will be used to forecast the vulnerability of appliances and electronic units that use this type connector.

The cooperation of the Rome Air Development Center, Griffiss AFB, New York was requested. All exposures and measurements were conducted at the Center with care and precision. The assistance of Mr. Q. Porter, Mr. J. Parry and the Rome Air Development Center is greatly appreciated.

Exposed circuits on circuit boards, uncoated contacts and uncovered connectors are the areas most susceptible to carbon fiber contamination in electronic devices. Connectors were investigated to relate the exposure to failure and the size of the airgap between the connectors. The standard Quick Disconnect Connector (see Figure 1 and the sketch below)



was selected for testing because of its wide use in appliances and electronic devices. Voltrex type CFS, 1/4 inch tab, vinyl insulated terminals with insulation removed were used. Results of testing are to be used in determining the exposure at which a pair of connectors will become shorted. Knowing the size of the airgap, the length of the fibers and the total number of connectors an exposure to failure can be forecast.

2.0 Test Plan

2.1 Method of Test

A test board was constructed and is pictured in Figure 2. Three sets of fourteen connectors spaced at 1/4, 1/2, and 3/4 inch (6mm, 13mm and 19mm respectively) were mounted with the flat side of the connectors facing up. Another three sets were mounted vertically with the edge pointed up. A shorting bar to simulate the case of a unit was mounted below each row of connectors. The connectors were exposed to Celanese GY-70 fibers of 3mm, 7mm, and 12mm lengths.

2.2 Test Circuit Description

The connectors had 115VAC applied and were connected to a current limited latching circuit with a light emitting diode indication. The circuit was designed to latch upon detecting the first short. The first failure on each of the 12 circuits (six sets of connectors and six combinations of connectors to shorting bar) was signalled by the light emitting diode (see Figure 3).

Every ten seconds, during the run, the twelve channels were scanned with a scanner and voltmeter and the data were stored. At the end of every ten second period the light emitting diode reset

switch was opened for 100 milliseconds to determine if the short was still present. Only the exposure at the first short was used in the analysis. Events where a short occurred and then fell off the connectors, was repelled or quit being a short were not considered. The response time of the test circuit was less than 17 milliseconds.

The data was also investigated to find the effect of not using exposures causing shorts of less than twenty seconds duration. This resulted in a slight change in the curve. The curve to the left of the Fiber Length/Airgap ratio of one was slightly changed. The portion to the right favored higher exposures by a factor of two. An example of one plot is shown in Figure 15. The original curve of Figure 6 is shown with a plot altered by requiring all shorts to last at least twenty seconds.

Exposure to fibers was continued until all circuits were shorted, or until an exposure of 10^8 fibers-seconds/meter³ was reached. Six runs were made at each fiber length and concentration was held between 10^3 and 10^5 fibers/meter³. Runs were made with the shorting bars horizontal (see Figure 2) and then repeated with the board rotated 90° and the bars vertical (see Figure 4).

Figure 5 shows a flow diagram of the test procedure. Appendix A shows circuit resistance parameters and operational characteristics.

3.0 Data Analysis

3.1 Average exposures to failure (\bar{E}) were calculated from the raw data and are shown for each fiber length, for each air gap spacing and for the various shorting possibilities of a connector to connector or connector to bar. Table 1 shows the \bar{E} 's and diagrams of the

connector and bar orientations. Each average is based on six test runs and \bar{E} computed as:

$$\frac{\Sigma 6 \text{ Exposures}}{6}$$

In runs where no failure occurred \bar{E} was calculated by subtracting the number of runs with no failure from the denominator. For instance if two of the six runs had no failure

$$\bar{E} = \frac{\Sigma 6 \text{ Exposures}}{6-2}$$

This method of accounting for runs with no failures was developed by the Ballistics Research Laboratory. Appendix B is an extract from Ballistics Research Laboratory, Aberdeen Maryland, Report dated 31 July 1978, which explains the calculation.

3.2 In analyzing the data, a ratio of fiber length divided by airgap was calculated. This makes the data non dimensional and may allow extrapolating the data to other spacings and fiber lengths. Figures 6 through 13 show the different plots.

Curve pairs 6 & 10 and 7 & 11 are similar with a maximum variation of approximately one half order of magnitude. These four curves are from runs with the connector rows and shorting bars horizontal. The other curves depict data from the connectors lined up in a vertical row and showed a higher exposure to failure with longer length fibers by slightly less than an order of magnitude. This should be expected since the top connectors shielded those below it in the vertical column.

The spread of points on the right hand side in curves 12 and 13 indicates more random capture characteristics and higher \bar{E} of a

vertical shorting bar or appliance case as opposed to a horizontal one.

3.3 By combining all eight curves on one chart and forming an envelope from the highest and lowest points, the upper and lower limits of Figure 14 are formed. All points from the previous figures, except Figure 12 and 13, lie within the envelope. The center curve represents a numerical average of the \bar{E} 's for all the connector and connector to shorting bar configurations.

It is believed this curve can be used to forecast equipment vulnerability within the limits shown. In any forecast it should be remembered fourteen connectors were used. A shorting bar of brass sheet metal $1\frac{1}{2}$ inches wide by 14 inches long was placed below or beside the connectors. If an appliance has more or less connectors the \bar{E} should be adjusted.

4.0 Conclusions

Vertically placed connectors, one under the other, are less vulnerable than horizontally placed connectors by almost an order of magnitude when the fiber length is longer than the airgap and the ratio of Fiber Length/Airgap is greater than one.

The \bar{E} of quick disconnect connectors is predictable depending on the airgap. Exposure to failure rises rapidly as the Fiber Length/Airgap ratio gets smaller since multiple fibers are required to bridge the airgap when the ratio is less than one.

Knowing the fiber length and airgap Figure 14 can be used to forecast the average exposure to failure within the limits shown. Figure 14 is calculated for seven pairs of connectors and the \bar{E} should be adjusted by dividing exposure by seven if only one pair

is being used. For other connectors, surface area should be considered.

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AVERAGE EXPOSURE TO FAILURE (\bar{E})


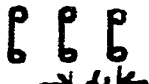

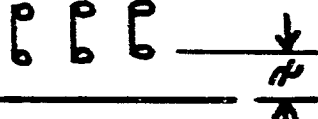
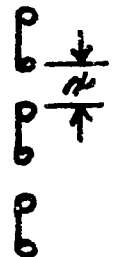
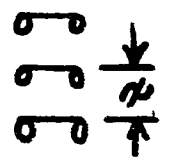
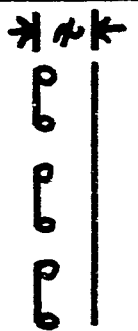
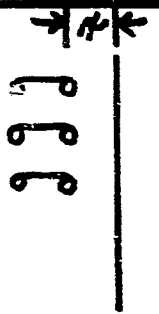
Fiber Length	 VALUES OF μ											
	1/4" (6mm)	1/2" (13mm)	3/4" (19mm)	1/4"	1/2"	3/4"	1/4"	1/2"	3/4"	1/4"	1/2"	3/4"
3mm	1×10^6	5×10^7	8×10^7	6×10^5	3×10^7	2×10^8	4×10^6	2×10^8	2×10^8	1×10^7	5×10^8	2×10^8
7mm	1×10^5	8×10^5	6×10^6	6×10^4	5×10^5	2×10^6	1×10^5	1×10^6	3×10^6	4×10^5	9×10^5	1×10^7
12mm	2×10^4	2×10^5	4×10^5	4×10^4	7×10^4	6×10^5	2×10^4	3×10^5	2×10^5	1×10^5	4×10^5	6×10^5
												
3mm	1×10^7	2×10^8	2×10^8	3×10^6	2×10^8	∞	1×10^7	2×10^8	1×10^7	1×10^7	3×10^8	∞
7mm	4×10^5	4×10^6	9×10^6	2×10^5	2×10^6	1×10^7	5×10^5	4×10^6	4×10^5	1×10^6	4×10^6	4×10^7
12mm	3×10^5	1×10^6	3×10^6	2×10^5	4×10^5	1×10^6	7×10^5	1×10^6	3×10^5	2×10^5	1×10^6	4×10^6

TABLE 1

NOTE: The x denotes air gap analyzed for short.

Sketch shows orientation of the row of connectors and shorting bar.

ORIGINAL PAGE 2
OF POOR QUALITY

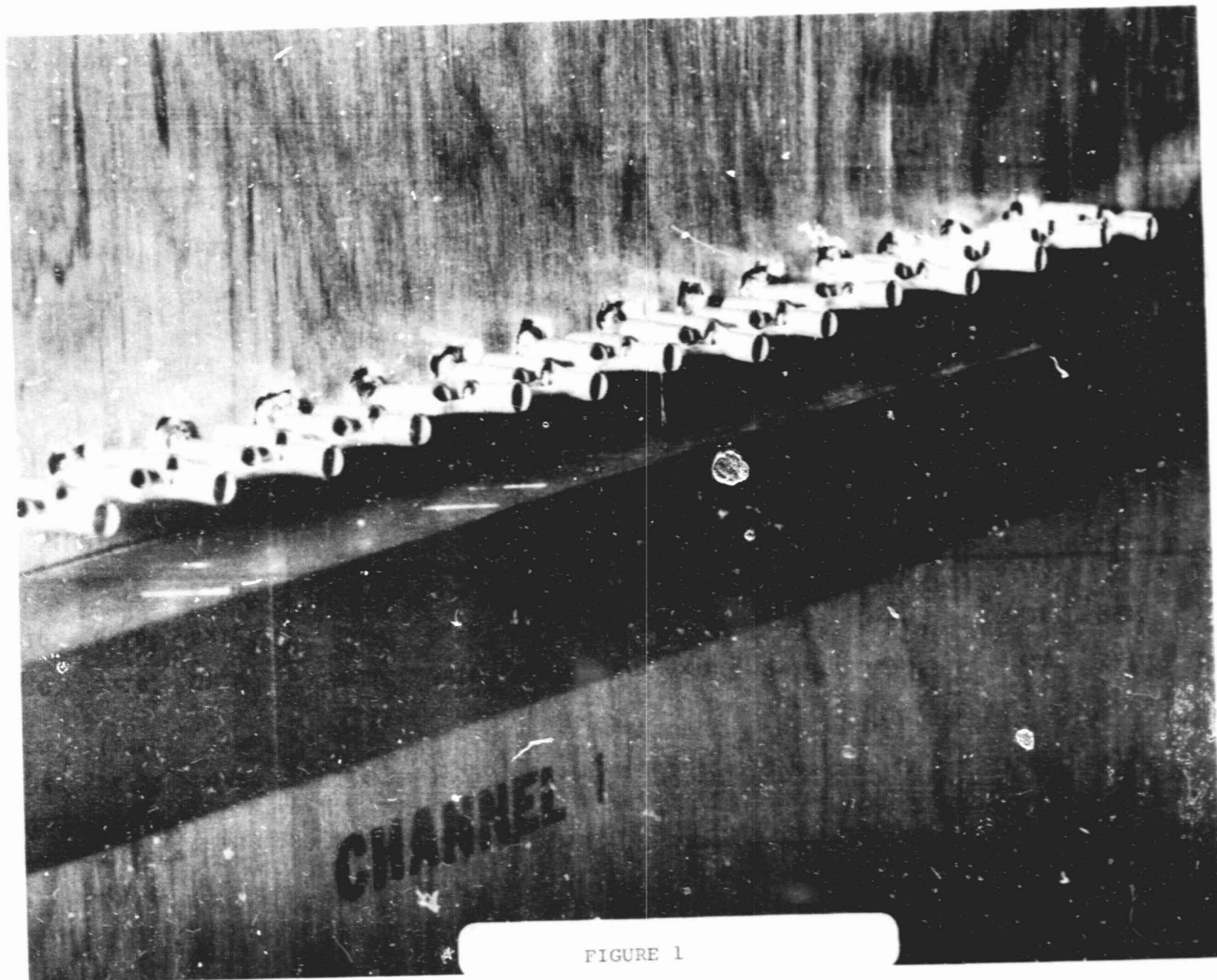


FIGURE 1

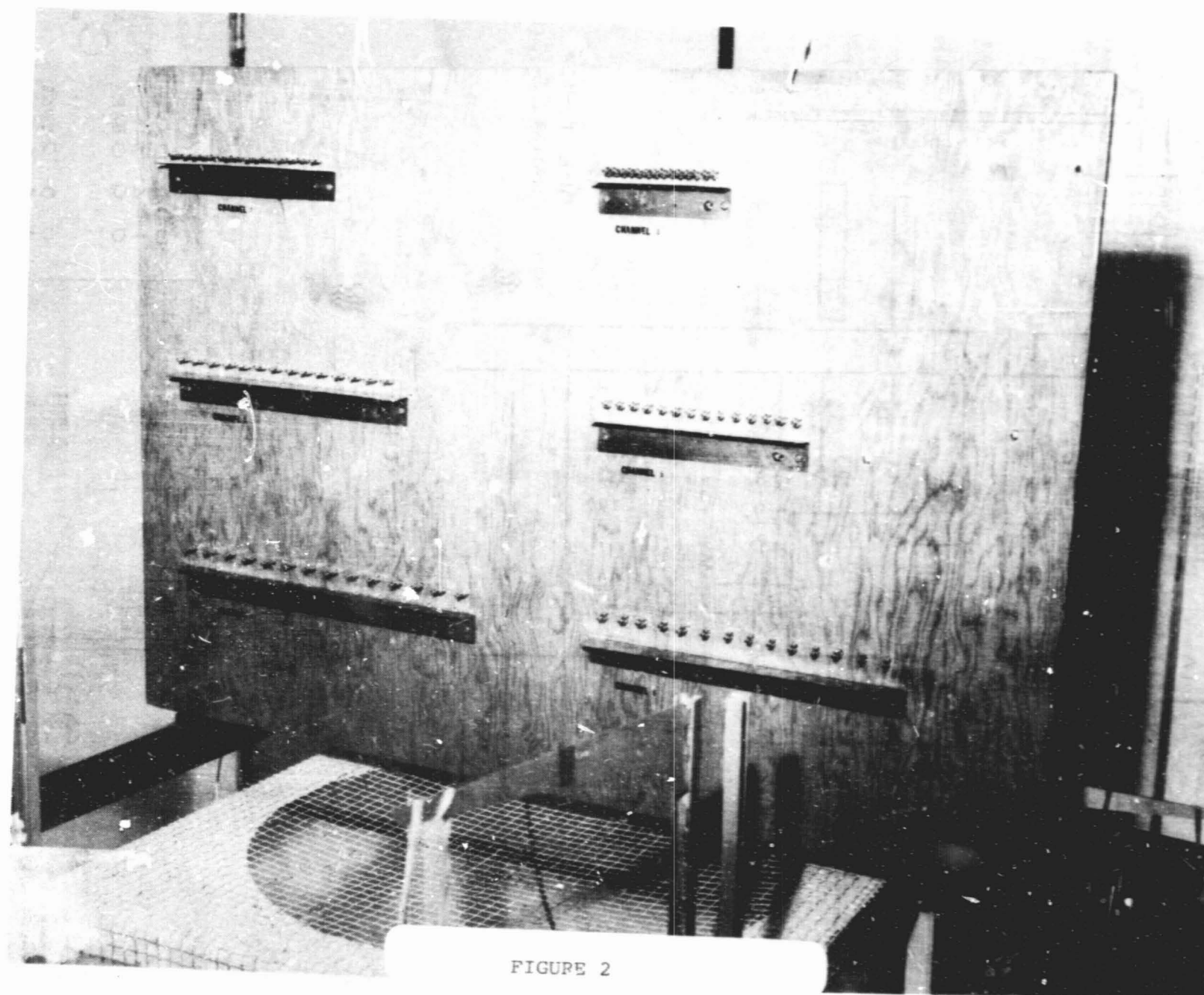
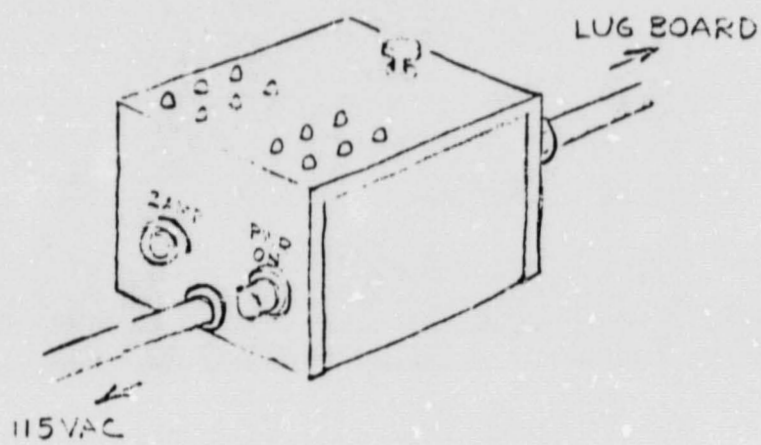
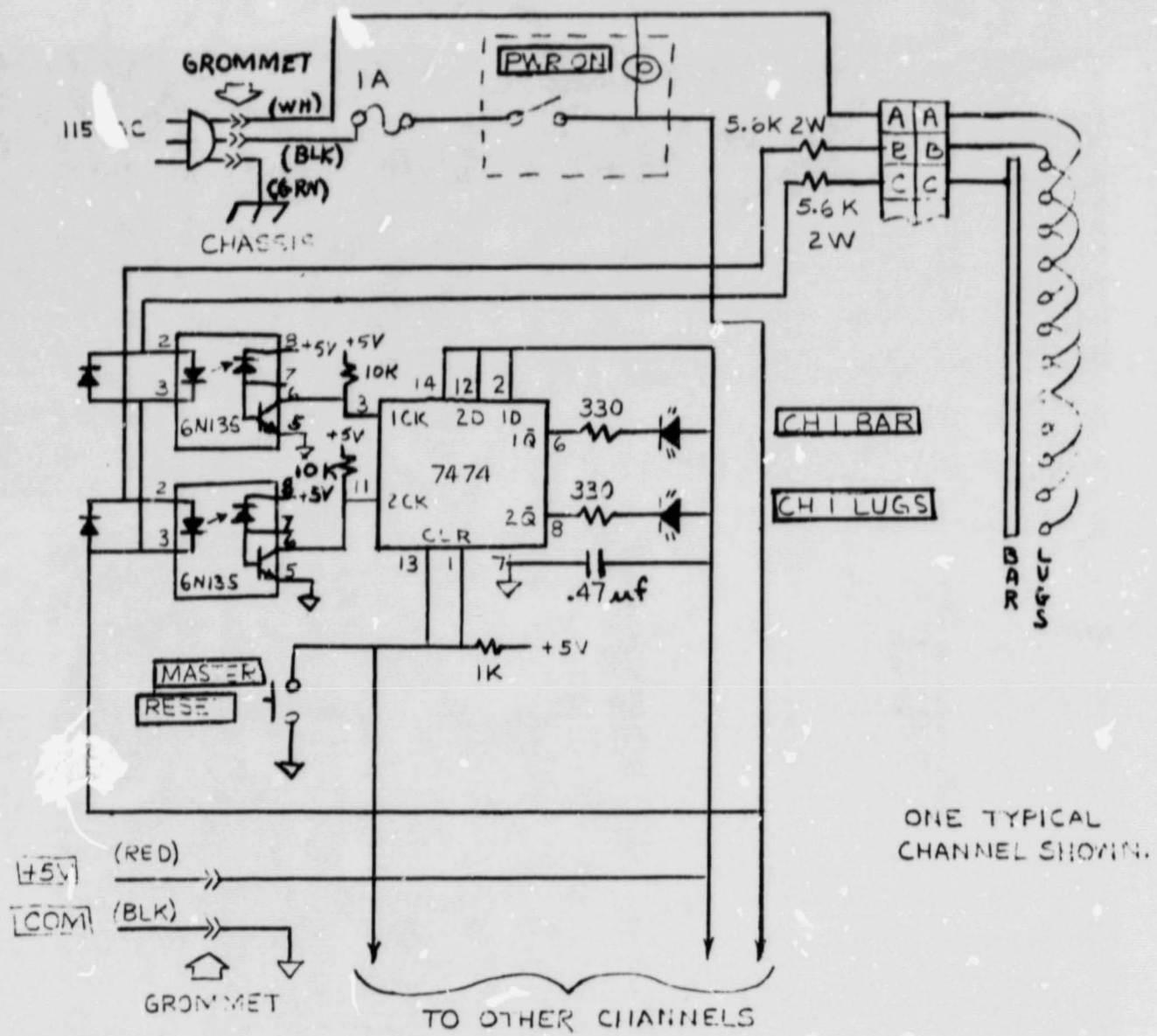


FIGURE 2

ORIGINAL PAGE IS
OF POOR QUALITY



0	0	0	LUGS
1	2	3	
0	0	0	BAR
0	0	0	LUGS
4	5	6	
0	0	0	BAR

MASTER
RESET

FIGURE 3

ORIGINAL PAGE IS
OF POOR QUALITY

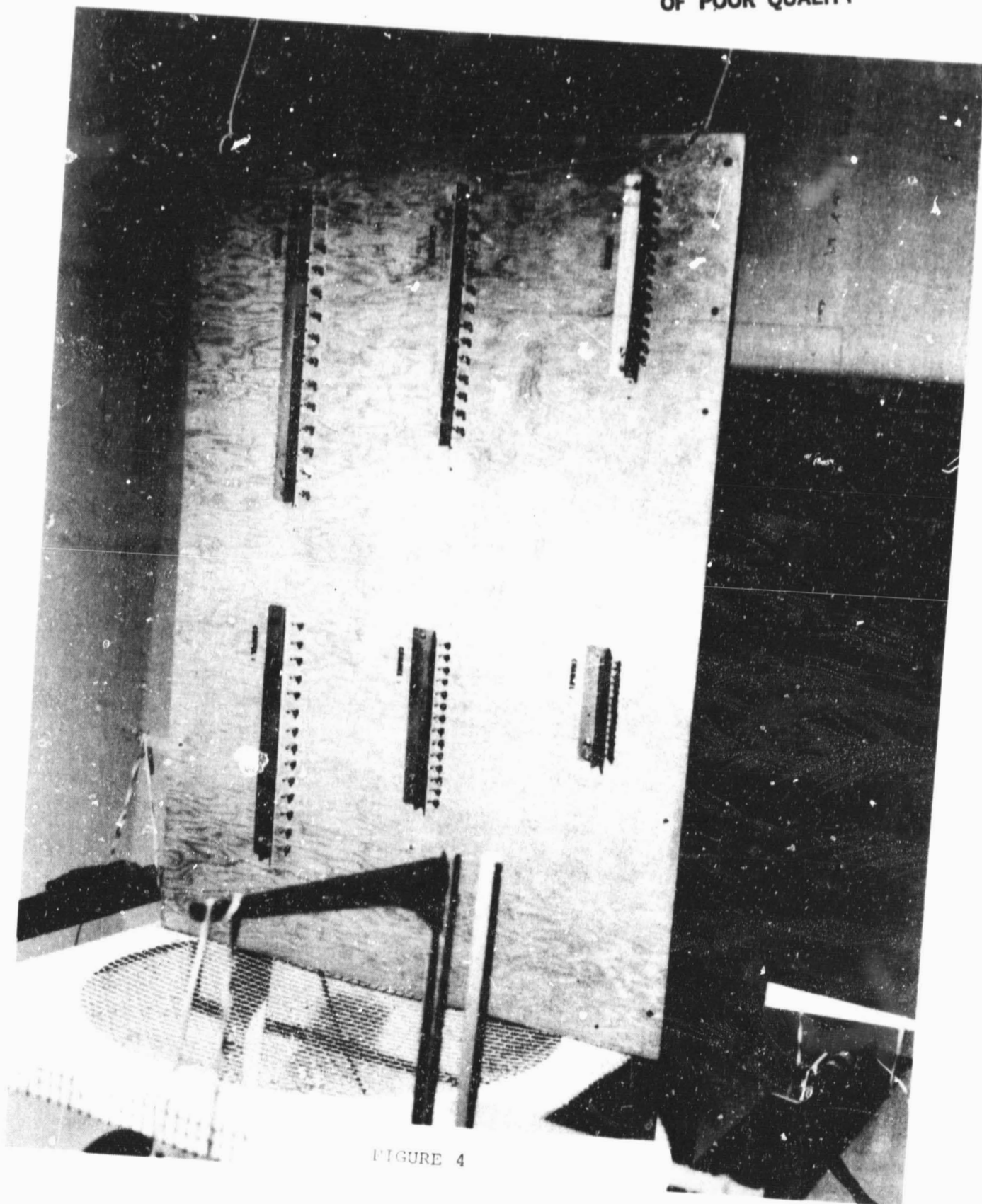


FIGURE 4

TEST RUN PROCEDURE

36 Runs Required

3 Fiber Lengths x 6 Runs x 2 Board Positions

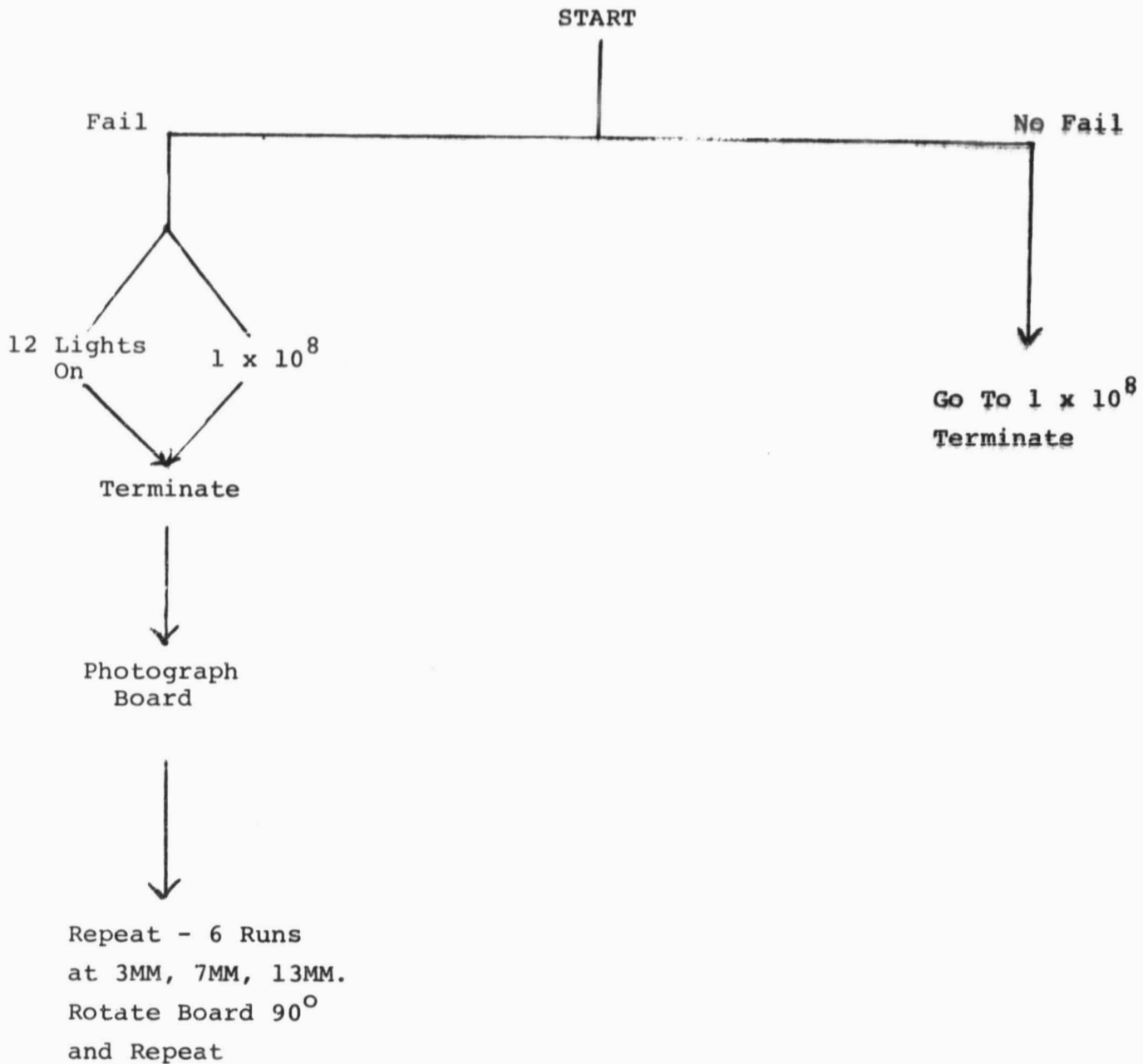


Figure 5

AVERAGE EXPOSURE TO FAILURE (\bar{E})
FIBER-SECONDS/METER³

1×10^5

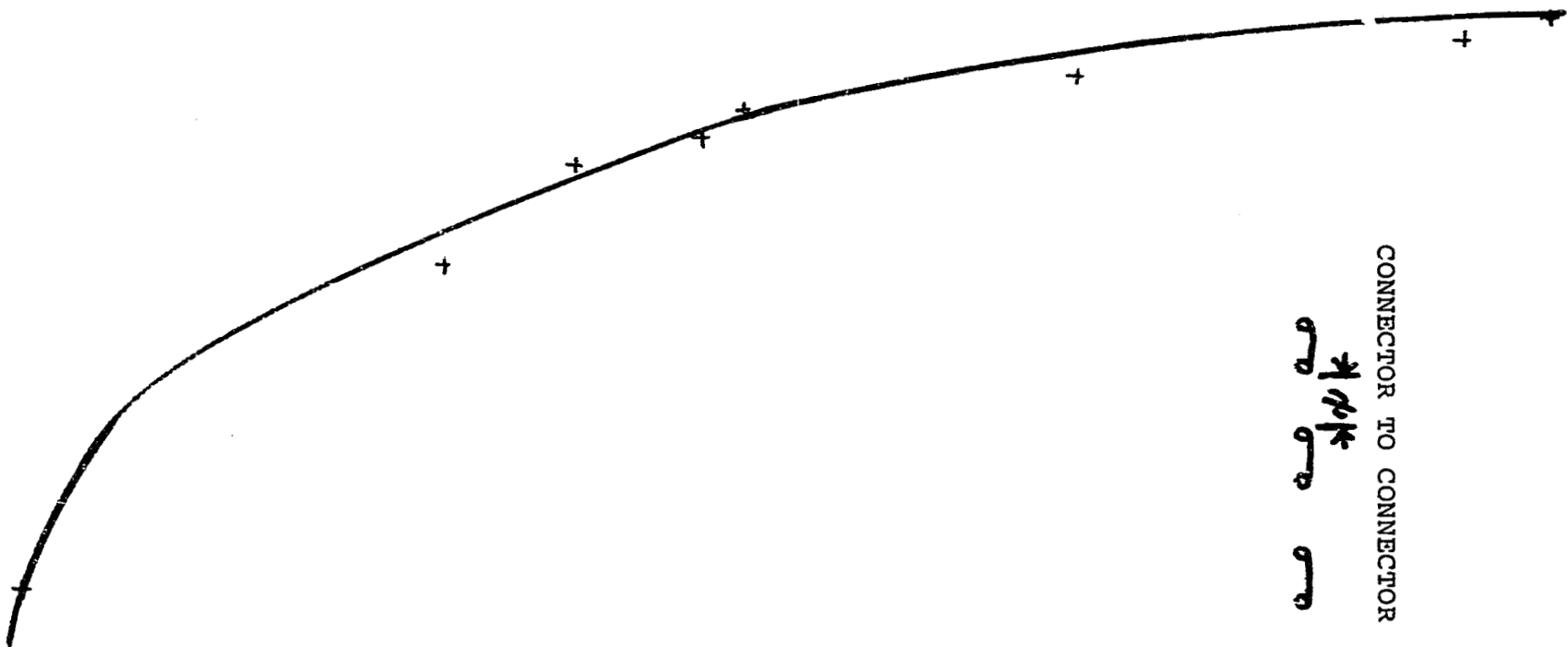
1×10^6

1×10^7

CONNECTOR TO CONNECTOR

3/2/76

FIBER LENGTH/AIRGAP
FIGURE 6



AVERAGE EXPOSURE TO FAILURE (\bar{E})

FIBER-SECONDS/METER³

1×10^5

1×10^6

1×10^7

CONNECTOR TO CONNECTOR

6666

.5

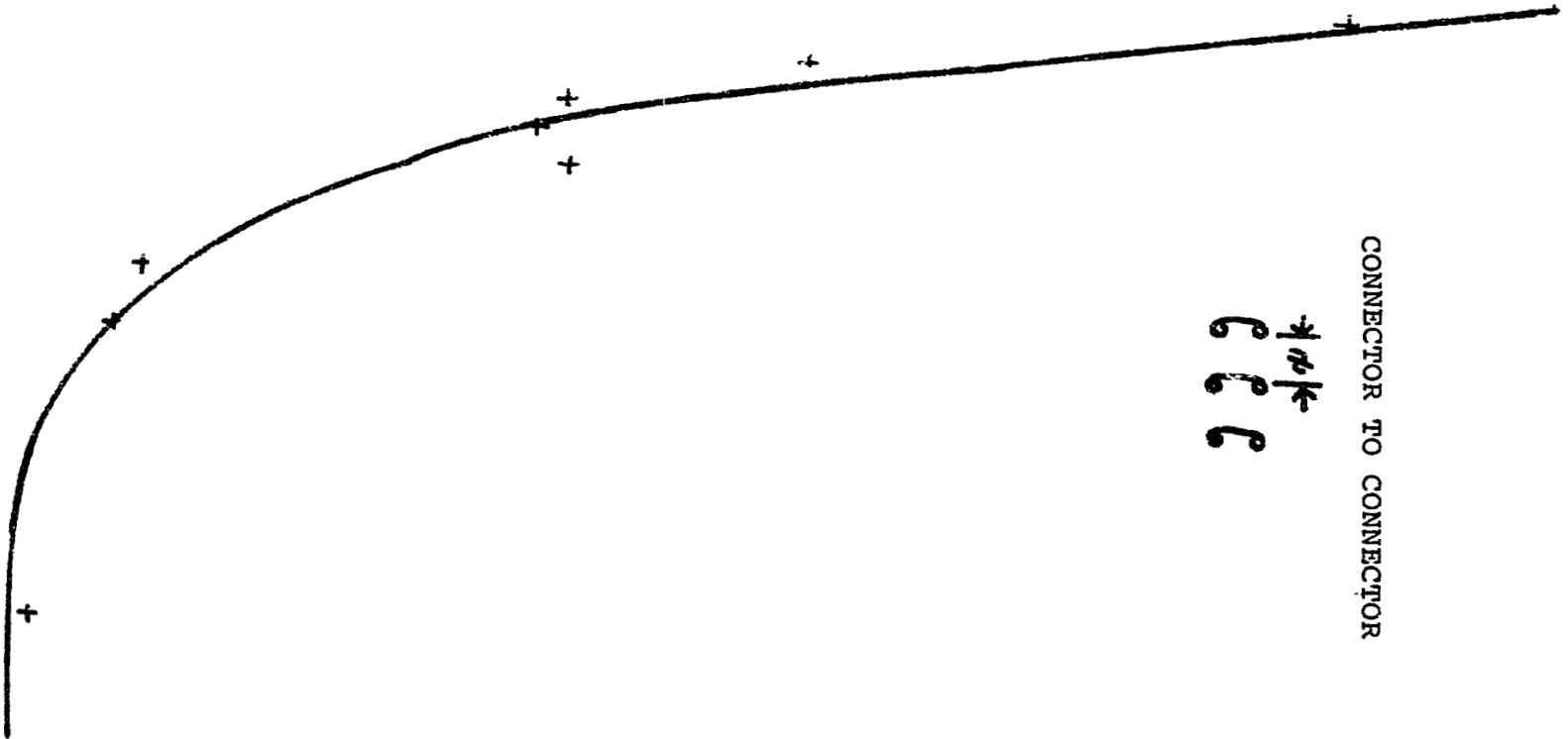
1.0

1.5

2.0

FIBER LENGTH/AIRGAP

FIGURE 7



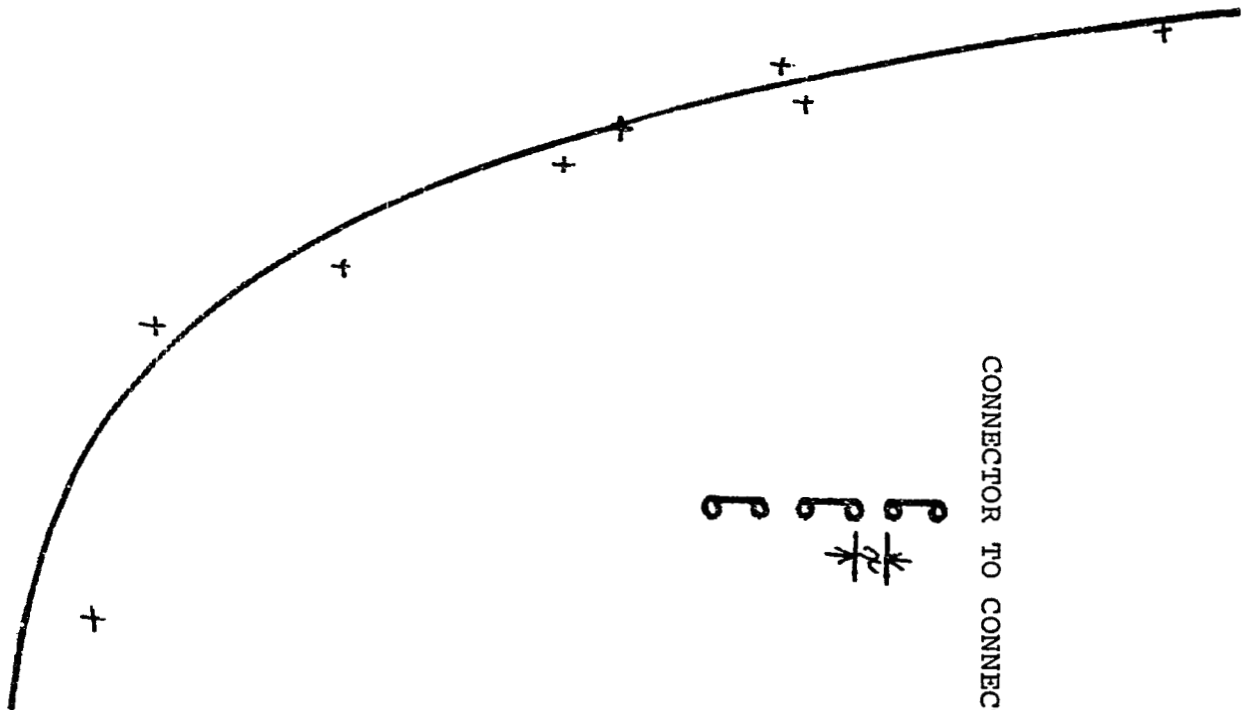
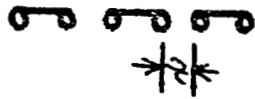
AVERAGE EXPOSURE TO FAILURE (\bar{E})
FIBER-SECONDS/METER³

10⁵

10⁶

10⁷

CONNECTOR TO CONNECTOR



FIBER LENGTH/AIRGAP

FIGURE 8

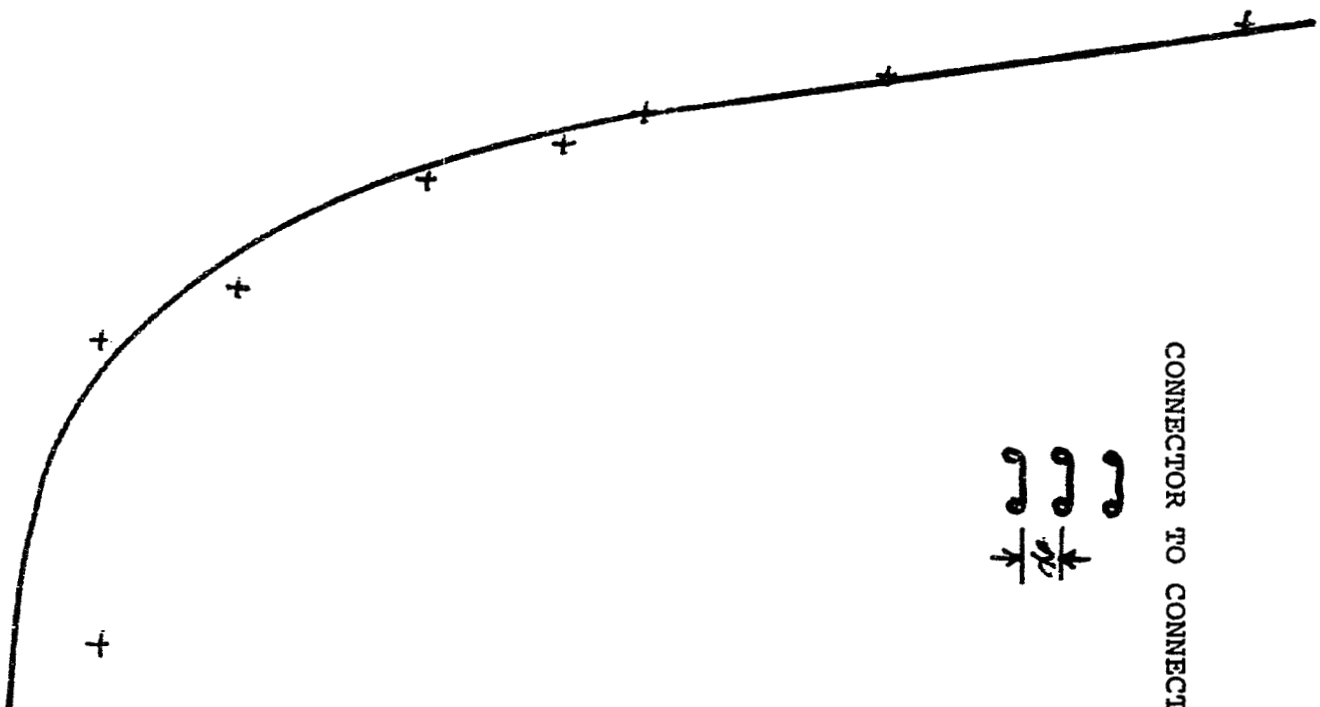
AVERAGE EXPOSURE TO FAILURE (\bar{E})
FIBER-SECONDS/METER³

10⁵

10⁶

10⁷

CONNECTOR TO CONNECTOR



FIBER LENGTH/AIRGAP

FIGURE 9

AVERAGE EXPOSURE TO FAILURE (\bar{E})
FIBER-SECONDS/METER³

10⁵

10⁶

10⁷

CONNECTOR TO BAR



.5 1.0 1.5 2.0

FIBER LENGTH/AIRGAP

FIGURE 10

AVERAGE EXPOSURE TO FAILURE (\bar{E})
FIBER-SECONDS/METER³

10⁵

10⁶

10⁷

.5

1.0

1.5

2.0

FIBER LENGTH/AIRCAP

CONNECTOR TO BAR
6666
—

#

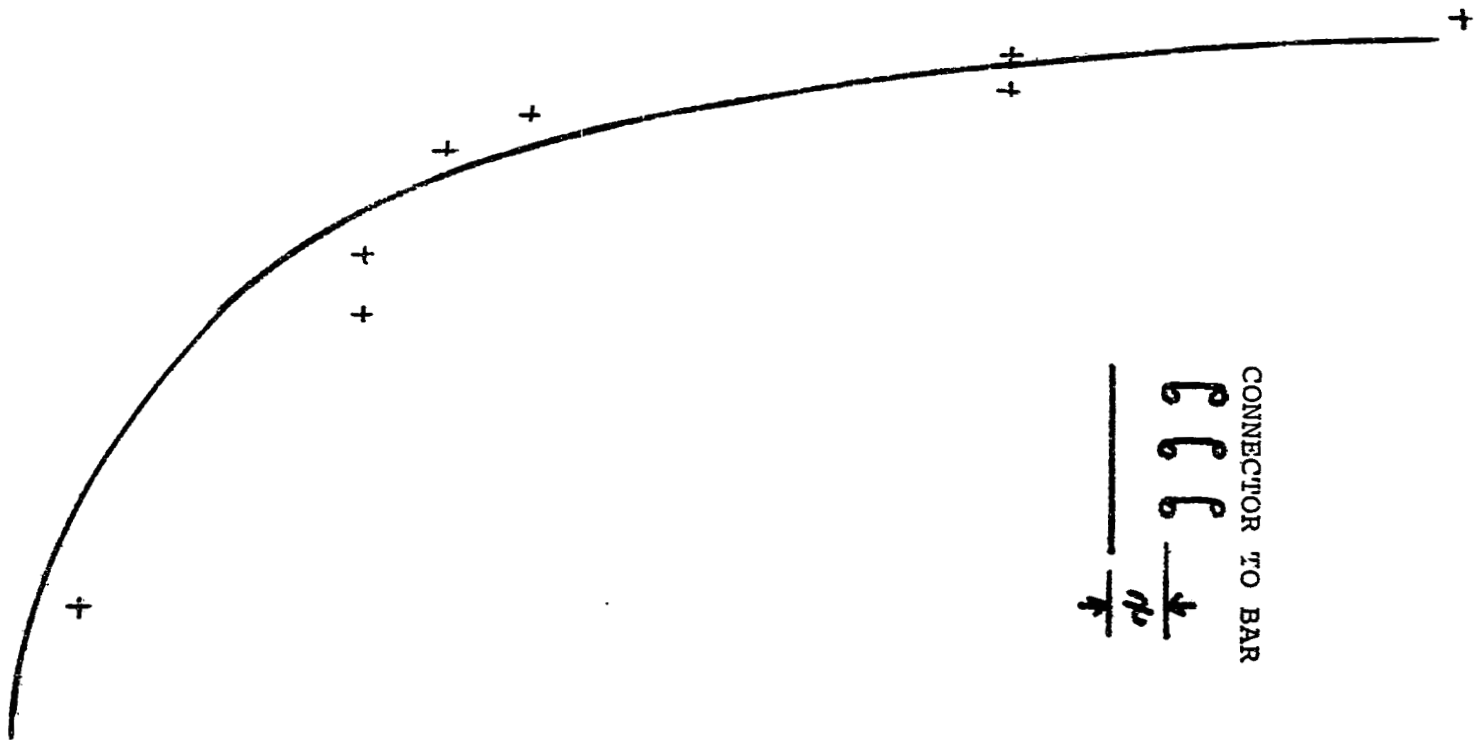


FIGURE 11

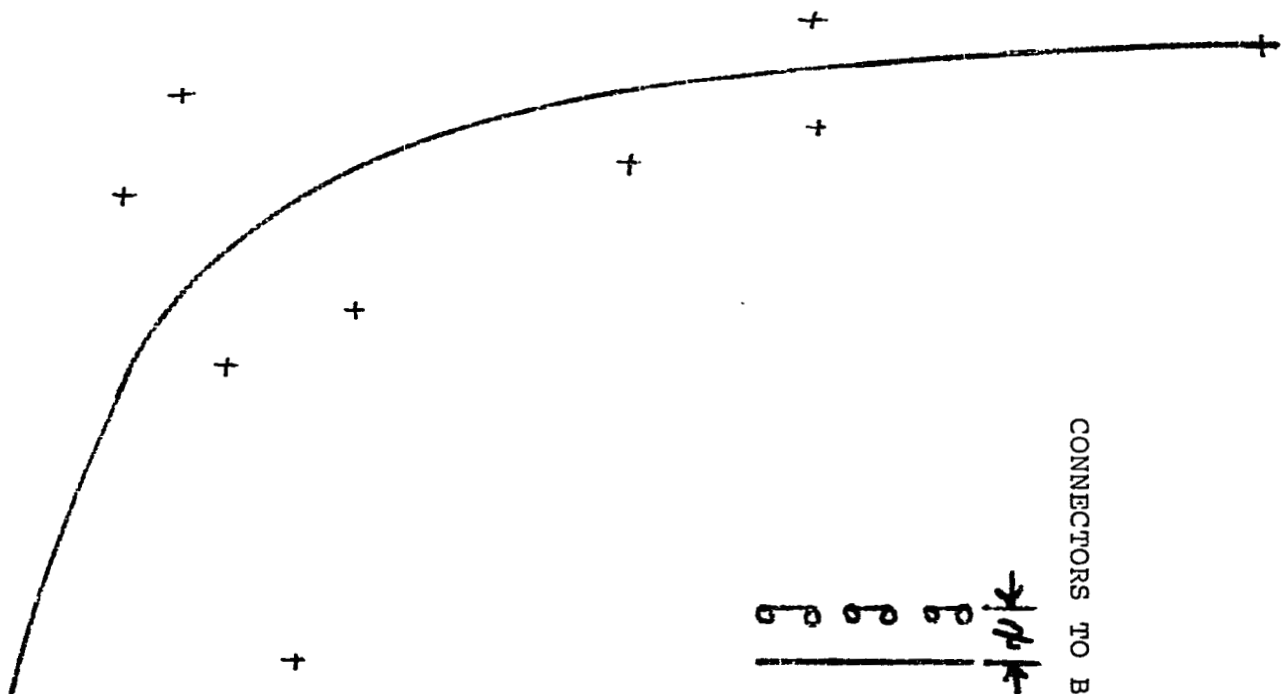
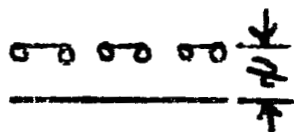
AVERAGE EXPOSURE TO FAILURE (E)
FIBER-SECONDS/METER³

10⁵

10⁶

10⁷

CONNECTORS TO BAR



.5

1.0

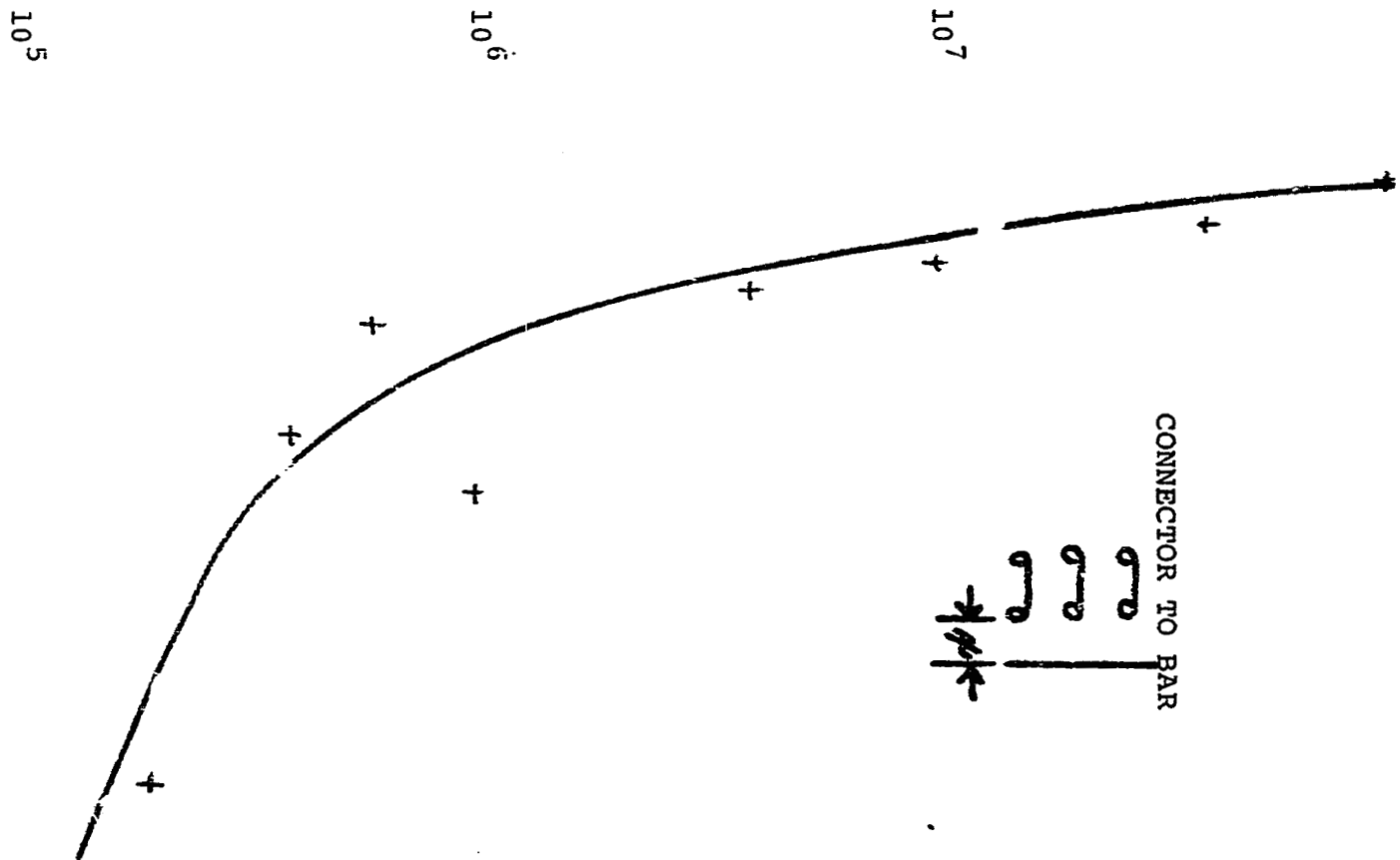
1.5

2.0

FIBER LENGTH/AIRGAP

FIGURE 12

AVERAGE EXPOSURE TO FAILURE (\bar{E})
FIBER-SECONDS/METER³



CONNECTOR TO BAR

FIBER LENGTH/AIRGAP

FIGURE 13

EXPOSURE TO FAILURE
FIBER-SECONDS/METER³

10⁵

10⁶

10⁷

ALL CONNECTOR CONFIGURATIONS COMBINED

UPPER LIMIT

NUMERICAL AVERAGE

LOWER LIMIT

.5

1.0

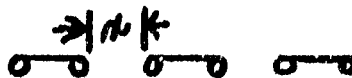
1.5

2.0

FIBER LENGTH/AIRGAP

FIGURE 14

CONNECTOR TO CONNECTOR



AVERAGE EXPOSURE TO FAILURE (\bar{E})
FIBER SECONDS/METER³

1×10^7

1×10^6

1×10^6

CURVE REQUIRING
ALL SHORTS TO LAST
AT LEAST 20 SECONDS

CURVE FROM
FIGURE 6

.5

1.0

1.5

2.0

FIBER LENGTH/AIRGAP
FIGURE 15

CIRCUIT RESISTANCE PARAMETERS

<u>Channel</u>	<u>Resistance to fire LED with Re- peated Making and Breaking</u>
1 Connector to Connector ($\frac{1}{4}$ ")	18.9 K
1 Connector to Bar ($\frac{1}{4}$ ")	18.6 K
2 Connector to Connector ($\frac{1}{2}$ ")	25.4 K
2 Connector to Bar ($\frac{1}{2}$ ")	19.2 K
3 Connector to Connector ($\frac{3}{4}$ ")	5.8 K
3 Connector to Bar ($\frac{3}{4}$ ")	17.9 K
4 Vertical Connector to Connector ($\frac{1}{4}$ ")	19.2 K
4 Vertical Connector to Bar ($\frac{1}{4}$ ")	18.2 K
5 Vertical Connector to Connector ($\frac{1}{2}$ ")	25.7 K
5 Vertical Connector to Bar ($\frac{1}{2}$ ")	20.5 K
6 Vertical Connector to Connector ($\frac{3}{4}$ ")	18.9 K
6 Vertical Connector to Bar ($\frac{3}{4}$ ")	15.5 K

Summary of Operational Characteristics
of Quick Disconnect Board

1. All channels are schematically identical.
2. All channels have the capacity to limit current to 20 ma RMS.
3. Total input current is fused at 1 ampere.
4. The circuit will detect only the first fiber that falls across a pair of contacts. The light emitting diode will then fire and latch.
5. Subsequent fibers cannot be detected unless the first fiber burns out or falls off the contacts and the circuit is reset.
6. If the circuit is reset with a fiber still across the contacts, the light emitting diode will not be extinguished.
7. Any fiber whose resistance plus contact resistance equals 15,500 ohms or less will be detected except at channel 3 connectors. (see APPENDIX A-1)
8. Testing shows that any channel may be occasionally fired by a short of 50,000 ohms.
9. Testing shows that shorts of 300 ohms cause reliable firings. Shorts lower than 100 ohms will cause channel interaction, i.e. other channels may be fired.
10. The circuit is not affected by power line surges or airborne electromagnetic transients; however quiet power lines and environment should be provided for best operation.

TEST DATA ANALYSIS

Estimate of the Exposure to Failure

To determine the best estimate of the average exposure to failure, $\langle E_0 \rangle$, assuming the single fiber model (exponential), the maximum likelihood estimate is used, that is

$$f = 1/\langle E_0 \rangle = m / \sum_{i=1}^n E_i$$

where n is the total number of experiments, E_i is the exposure to which the i^{th} test is run, and m is the number of failures. The special case where there are no failures is treated later.

Examples

Applying the above methodology to example data, we compute the point estimates of the exposures to failure and then use the point estimate to construct the confidence limits for the exposure to failure.

The same values of E_i are used in each example to illustrate the effect of "no malfunction", (runs that did not fail) on $\langle E \rangle$.

Example 1.

Item A is tested five (5) times and malfunctions (fails) every time at the E_i shown.

<u>Test Number</u>	E_i (fs/m ³)
1	1×10^6
2	1×10^7
3	5×10^6
4	5×10^6
5	8×10^6
$n = 5$	$m = 5$

$$\langle E_O \rangle = \frac{\sum_{i=1}^n E_i}{m} = \frac{2.9 \times 10^7}{5}$$

$$\langle E_O \rangle = 5.8 \times 10^6 \text{ fs/m}^3$$

Example 2.

Item B is tested five (5) times and malfunctions on three (3) tests. On the two tests where there were no malfunctions, the tests were terminated at E_i , shown as $\langle E_i \rangle$.

<u>Test Number</u>	<u>E_i (fs/m³)</u>
1	1×10^6
2	$(>1 \times 10^7)$ no malfunction
3	5×10^6
4	5×10^6
5	$(>8 \times 10^6)$ no malfunction
$n = 5$	$m = 3$

$$\langle E_O \rangle = \frac{\sum_{i=1}^n E_i}{m} = \frac{2.9 \times 10^7}{3}$$

$$\langle E_O \rangle = 9.7 \times 10^6 \text{ fs/m}^3$$